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Stability Properties  
in a Growth Model

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and  
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**Stability Properties in a Growth Model**

**ALESSANDRA PELLONI  
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# Stability properties in a growth model\*

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## Abstract

The inclusion of a labour/leisure choice in endogenous growth models has interesting and somewhat counter-intuitive effects. In existing one sector models, a condition for indeterminacy is that labour demand is upward-sloping, which is difficult to reconcile with the evidence. In this paper we give conditions for indeterminacy in a one sector model with decreasing returns to labour. We show that this requires that consumption and leisure are both highly intertemporally substitutable while the factors of production are highly complementary.

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# 1 Introduction

In this paper we study whether the market outcome can be indeterminate in a one sector model of endogenous growth, where agents elastically supply labour and there are decreasing returns to labour. Recently there has been a renewed interest in the problem of indeterminacy of equilibria in growth models.<sup>1</sup> As is well, known indeterminate steady states are associated with a continuum of rational expectations equilibria driven by self-fulfilling beliefs. These are dynamic examples of what Shell (1977) labeled “sunspot equilibria” and have welfare properties different from those of equilibria that depend only on fundamentals. In a growth framework, the existence of a continuum of equilibria means that countries with identical tastes technology and initial endowments will converge to the same constant growth rate only in the very long run— while the level of income will remain different for ever. This seems an explanation deserving investigation for the differences in the growth patterns of the various countries observed in reality. The models suggest the possibility that appropriate policy interventions will in fact raise welfare, acting as selection devices for equilibria that differ during the transition interval. In fact cultural and institutional features in general may be seen as playing this same role.

To our knowledge, in existing one sector models a condition for indeterminacy is the presence of increasing returns to labour in the production of the factor that can be accumulated whether it is physical capital, human capital or knowledge. That labour demand slopes up is highly controversial and indeed very difficult to reconcile with evidence, so these models tend to fail empirically.<sup>2</sup> In this paper we give conditions for indeterminacy in a one sector model with decreasing returns to labour. We show that this requires that consumption and leisure are both highly intertemporally substitutable while the factors of production are highly complementary. A heuristic explanation is the following: starting from an optimal path, if one attempts to construct a new equilibrium by increasing consumption, then, if the elasticity of substitution of consumption is more than one, leisure will increase as well. If the elasticity of substitution between labour and capital is low, the reduction in labour supply will cause a sharp decline in the interest rate. But with a high elasticity of substitution of consumption this can cause an even sharper decline in the rate of growth of

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<sup>1</sup>See among others, Chamley (1993), Benhabib and Farmer (1994), Benhabib and Perli (1994), Benhabib and Rustichini (1994), Gali (1994), Xie(1994), Benhabib and Gali(1995), Farmer and Guo(1995), etc.

<sup>2</sup>See Farmer and Guo(1995) and the comment by Ayagari(1995).

consumption, which can decline even more than the rate of growth of capital. Thus the economy would return to the balanced growth path.

The paper has four sections the first of which is this introduction. The second presents a model of unbounded accumulation with leisure in the utility function and gives general conditions for indeterminacy. The third provides an example by selecting specific functional forms for tastes and technology. The fourth draws conclusions.

## 2 A Model

We present a simple endogenous growth model with variable labour supply. All worker/consumers are identical and maximize the same CES inter-temporal utility function, multiplicatively separable in consumption of the homogeneous good  $C$  and the amount of labour they supply,  $L \in [0, 1]$ :

$$V = \int_0^\infty e^{-\rho t} \frac{C^{1-\sigma}}{1-\sigma} h(L) dt \quad (1)$$

where  $h(L)$  is twice differentiable and the following two conditions must hold for utility to be increasing in consumption and decreasing in labour:

$$h(L) > 0 \quad (2)$$

$$(1 - \sigma)h'(L) < 0 \quad (3)$$

while the following two conditions must hold for concavity:

$$(1 - \sigma)h''(L) < 0 \quad (4)$$

$$\frac{\sigma}{(\sigma - 1)} h''(L) h(L) > (h'(L))^2 \quad (5)$$

We assume that there is a continuum of competitive firms. As is standard from Romer (1986) we assume that the production set at the firm level is convex in labour  $L$  and capital  $K$  but that average capital  $\bar{K}$  causes a labour augmenting spill-over which is taken as given by each firm, so that the social production function is linear in capital. With population normalized to unity production  $Y$  is then given by equation 6

$$Y = F(\bar{L}\bar{K}, K) = KF(L, 1) \equiv Kf(L) \quad (6)$$



where  $f(0) = 0$ ,  $f' > 0$ ,  $f'' < 0$ . Profit maximization by firms and perfect competition give the wage and real interest rate:

$$W = K f'(L) \quad (7)$$

and

$$r = f(L) - f'(L)L \quad (8)$$

Equation 9 gives the instantaneous budget constraint consumers face:

$$\frac{\dot{K}}{K} = r + \frac{WL}{K} - \frac{C}{K} \quad (9)$$

The static first order condition for the choice between labour and leisure is:

$$C = \frac{(\sigma - 1)h(L)W}{h'(L)} \quad (10)$$

The consumers consumption savings choice implies:

$$r - \rho = \sigma \frac{\dot{C}}{C} - \frac{h'(L)}{h(L)} \frac{\dot{L}}{L} = \left( -\sigma \frac{h''(L)}{h'(L)} + (\sigma - 1) \frac{h'(L)}{h(L)} \right) \frac{\dot{L}}{L} + \sigma \frac{\dot{W}}{W} \quad (11)$$

where the second equality is obtained by differentiating the first order condition for consumption and leisure 10.

The instantaneous budget constraint 9 and the first order condition 10 imply:

$$\frac{\dot{K}}{K} = f(L) + (1 - \sigma) \frac{h(L)}{h'(L)} f'(L) \quad (12)$$

Differentiating 7 considering 12, and substituting in 11 we get:

$$\left( -\sigma \frac{h''(L)}{h'(L)} - (1 - \sigma) \frac{h'(L)}{h(L)} + \sigma \frac{f''(L)}{f'(L)} \right) \frac{\dot{L}}{L} = r - \rho - \sigma \frac{\dot{K}}{K} = r - \rho - \sigma \left( f(L) + (1 - \sigma) \frac{h(L)}{h'(L)} f'(L) \right) \quad (13)$$

Balanced growth  $\tilde{L}$  (whicis not necessarily unique) is then given by:

$$\rho = (1 - \sigma)f(\tilde{L}) - \left( \tilde{L} + \sigma(1 - \sigma) \frac{h(\tilde{L})}{h'(\tilde{L})} \right) f'(\tilde{L}) \quad (14)$$

The transversality condition that the present value at time zero of the capital stock as time goes to infinity goes to zero can be written as:

$$\lim_{t \rightarrow \infty} h(L) C^{-\sigma} K \exp(-\rho t) = 0 \quad (15)$$

and implies that  $\rho > g(1 - \sigma)$  where  $g$  indicates the asymptotic rate of growth. We have  $g = (r(\tilde{L}) - \rho) / \sigma$  with  $r(\tilde{L})$  being the asymptotic rate of interest. The transversality condition then also implies  $r(\tilde{L}) > g$  or  $\rho > (1 - \sigma)r(\tilde{L})$ . By substituting in this last inequality the value for  $\rho$  given by 14 and rearranging we get 16 which we will use later.

$$\tilde{L} - (\sigma - 1) \frac{h(\tilde{L})}{h'(\tilde{L})} = \tilde{L} - \frac{C}{W} < 0 \quad (16)$$

We now analyse the dynamic nature of the steady state equilibrium. If this is stable when the economy is near balanced growth and labour supply drops slightly while consumption increases slightly then labour supply returns to its balanced growth level and the consumption capital ratio returns to its balanced growth level. Such stability implies indeterminacy – Consumption and labour supply can take a range of values each consistent with utility maximization and perfect foresight. As is well known, this in turn means that economically irrelevant publicly observable variables (sunspots) can effect the economy, even if all agents are rational utility maximizers with rational expectations. This is of some interest, since the effects of such a sunspot are permanent. The long run expected value of labour supply and of the consumption capital ratio are not affected by the sunspot, but the level of consumption and the capital stock are affected.

The coefficient of  $\tilde{L}$  in 13 is always negative. In fact, 5 can be rewritten as  $\sigma \frac{h''(\tilde{L})}{h'(\tilde{L})} + (1 - \sigma) \frac{h'(\tilde{L})}{h(\tilde{L})} > 0$ . The balanced growth path is then locally indeterminate if and only if:

$$\left( \tilde{L} + \sigma(1 - \sigma) \frac{h(\tilde{L})}{h'(\tilde{L})} \right) f''(\tilde{L}) + \left( \sigma + \sigma(1 - \sigma) \left( 1 - \frac{h(\tilde{L})h''(\tilde{L})}{(h'(\tilde{L}))^2} \right) \right) f'(\tilde{L}) < 0 \quad (17)$$

In 17 the coefficient of  $f'(\tilde{L})$  is positive both for  $\sigma < 1$  and for  $\sigma > 1$ ; in fact 5 implies

$$1 + (1 - \sigma) \left( 1 - \frac{h(\tilde{L})h''(\tilde{L})}{(h'(\tilde{L}))^2} \right) > 1 + 1 - \sigma - \frac{(1 - \sigma)^2}{\sigma} = \frac{1}{\sigma} \quad (18)$$

A necessary condition for stability is therefore that the coefficient of  $f''(\tilde{L})$  in 17 is positive. From 16 it's easy to infer that for  $\sigma > 1$  we have  $\tilde{L} + \sigma(1 - \sigma) \frac{h(\tilde{L})}{h'(\tilde{L})} = \tilde{L} - \sigma \frac{C}{W} < 0$ .

A first result is then that for  $\sigma > 1$  any balanced growth equilibrium is locally unstable. Since  $\tilde{L}$  is a continuous function of  $L$  local instability implies



global instability. Thus, balanced growth equilibrium is unique for  $\sigma$  greater than one.

In contrast, for any  $\sigma$  less than one, for any  $h(L)$  such that 19 holds there is a production function such that the economy has a stable and indeterminate growth path.

$$1 - \sigma(\sigma - 1) \frac{h(1)}{h'(1)} > 0 \quad (19)$$

For stability it is necessary that  $L - \sigma \frac{C}{W}$  is positive.  $L - \sigma \frac{C}{W} = L + \sigma(1 - \sigma) \frac{h(L)}{h'(L)}$  is increasing in  $L$  as for  $\sigma < 1$ ,  $h(L)$  is decreasing in  $L$  while  $|h'(L)|$  is increasing in  $L$ . Therefore assumption 19 and the fact that  $-\sigma \frac{C(0)}{W(0)}$  is negative allow us to infer that there is a  $L^*$  such that  $L^* - \sigma \frac{C(L^*)}{W(L^*)} = 0$ . From 16 we can then see that if  $L^*$  is the balanced growth labour supply, the transversality condition is respected.  $L^*$  is the balanced growth labour supply if  $\rho = (1 - \sigma)f(L^*)$ . Now consider  $L^{**}$  slightly greater than  $L^*$ . The right hand side of 14 is continuous in  $L$  so  $L^{**}$  is the balanced growth labour supply for some positive  $\rho$  close to  $(1 - \sigma)f(L^*)$ .<sup>3</sup> Since  $L - \sigma \frac{C}{W}$  is increasing in  $L$ , this means that for any  $\sigma < 1$ , for any  $h(L)$  such that 19 holds there is a positive  $\rho$  such that, in balanced growth  $\tilde{L}$ , inequality 20 holds

$$\tilde{L} - \sigma \frac{C}{W} > 0 \quad (20)$$

Notice that  $f''$  does not appear either in 14 or in 20. This means that we can consider different production functions which give the same balanced growth  $\tilde{L}$  and the same balanced growth  $\frac{C}{K}(\tilde{L})$  and  $f'(\tilde{L}) = \frac{W}{K}(\tilde{L})$  but have different  $f''(\tilde{L})$ . In particular, for fixed balanced growth  $(\tilde{L})$ ,  $\frac{C}{K}(\tilde{L})$  and  $\frac{W}{K}(\tilde{L})$ , there is a  $f''(\tilde{L})$  so far below zero that the condition for local stability 17 holds.

In conclusion we have shown that for any  $\sigma$  less than one, for any  $h(L)$  such that  $1 - \sigma(\sigma - 1) \frac{h(1)}{h'(1)} > 0$ , there are  $\rho$  and  $f(L)$  such that the balanced growth path is stable and indeterminate.

To sum up, for stability to obtain it is necessary i) that the elasticity of substitution of capital and labour is low so that the wage falls sharply and the interest rate rises sharply as labour supply increases and ii) that  $\sigma$  is small so that the marginal utility of consumption declines only slowly as consumption increases.

A heuristic explanation of the importance of a high elasticity of consumption ( $\sigma < 1$ ) for stability is the following: for stability it is necessary that if the

<sup>3</sup>For stability it is necessary that  $L - \sigma \frac{C}{W}$  is positive, so for  $\rho = (1 - \sigma)f(L^*)$ , the equilibrium is unstable. This means that differentiating 14 we have  $\frac{d\rho}{dL}(L^*) < 0$ .



initial consumption to capital ratio is slightly higher than balanced growth consumption to capital ratio then the rate of growth of consumption is lower than the rate of growth of capital. High initial consumption can imply a low rate of consumption if leisure is a normal good (as it must be if  $\sigma < 1$ ) so high initial consumption implies low initial labour supply. If the elasticity of substitution between labour and capital is low the reduction in labour supply will cause a sharp decline in the interest rate. But with a high elasticity of substitution of consumption this can cause an even sharper decline in the rate of growth of consumption which can decline even more than the rate of growth of capital. Thus the economy can return to the balanced growth path.

A simple diagrammatic analysis can help in clarifying the issue of the stability of equilibrium. Figures 1 and 2 show, as functions of  $L$ , the  $\frac{K}{K}$  curve, that is, the budget constraint, and the  $\frac{r-\rho}{\sigma}$  curve—which equals  $\frac{\dot{C}}{C}$  if  $L = \tilde{L}$  is constant. At balanced growth  $\tilde{L}$  the  $\frac{K}{K}$  curve intersects the  $\frac{r-\rho}{\sigma}$  curve. If the  $\frac{K}{K}$  curve cuts the  $\frac{r-\rho}{\sigma}$  curve from above, as in figure 1, the balanced growth path is stable, while if the  $\frac{K}{K}$  curve cuts the  $\frac{r-\rho}{\sigma}$  curve from below, as in figure 2, the balanced growth path is unstable. This is clear from inspection of equation 13, given that the coefficient of  $\tilde{L}$  in the equation is always negative.<sup>4</sup>

## 2.1 An Example of Dynamic Stability

In this section we provide an example of an endogenous growth model with elastic labour supply with a dynamically stable and indeterminate balanced growth path, by choosing specific functional forms for  $h(L)$  and  $f(L)$ . We consider the case in which

$$h(L) = (1 - L)^{1-\alpha} \quad (21)$$

On the technology side we consider a CES production function with a labour augmenting spill-over to capital and elasticity of substitution of  $\frac{1}{1-\phi}$ .

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<sup>4</sup>Notice that both the  $\frac{r-\rho}{\sigma}$  curve and the  $\frac{K}{K}$  curve always slope up. In fact for the former this is immediate since the rate of interest is increasing in labour. For the latter differentiating the right hand side of 9 with respect to labour we find:

$$(1 - \sigma) \frac{h}{h'} f'' + \sigma \left( 1 + (1 - \sigma) \left( 1 - \frac{hh''}{(h')^2} \right) \right) f' > 0$$

as we know from 18 and the conditions for concavity of  $f$  and the utility function.

must be less than one for the production possibilities set to be convex. So we have:

$$Y = A \left( \alpha (\bar{K}L)^\phi + (1 - \alpha)K^\phi \right)^{\frac{1}{\phi}} \quad (22)$$

where  $A$  is a scale factor and  $\alpha \in (0, 1)$ .

Using the fact that  $L^\phi = \frac{1-\alpha}{\alpha} \frac{S_L}{1-S_L}$ , where  $S_L$  indicates the income share of labor and rearranging inequality 17 becomes inequality 23

$$\tilde{L} \left( (\phi - 1) \left( 1 + \frac{\sigma(1 - \sigma)}{(1 - \chi)} \right) (1 - S_L) + \sigma \frac{(2 - \sigma - \chi)}{(1 - \chi)} \right) < \frac{\sigma(\phi - 1)(1 - \sigma)(1 - S_L)}{(1 - \chi)} \quad (23)$$

We introduce the variable  $v \equiv \frac{r}{g}$ , that is the ratio between the interest rate and the balanced growth rate in balanced growth. Notice that the transversality condition implies that  $v$  is greater than one. The balanced growth labour supply can be expressed as

$$\tilde{L} = \frac{\frac{1-\sigma}{1-\chi} \frac{S_L}{(1-S_L)}}{\frac{S_L}{(1-S_L)} \frac{2-\sigma-\chi}{1-\chi} + \frac{v-1}{v}} \quad (24)$$

To obtain 24 we have proceeded as follows. Noticing that  $\rho = r(1 - \frac{\sigma}{v})$  and recalling that  $r = f - Lf'$ , given the specification in 21 for  $h(L)$ , 14 can be rewritten as  $-\frac{r}{v} = -f + \frac{1-\sigma}{1-\chi}(1 - \tilde{L})f'$ , and given 22 as:

$$\frac{(1 - \alpha)}{v} (\bullet)^{\frac{1}{\phi}-1} = -(\bullet)^{\frac{1}{\phi}} + \frac{1 - \sigma}{1 - \chi} (1 - \tilde{L}) (\bullet)^{\frac{1}{\phi}-1} \tilde{L}^{\phi-1} \quad (25)$$

where  $(\bullet) = (\alpha \tilde{L}^\phi + 1 - \alpha) = \frac{(1-\alpha)}{(1-S_L)}$ . Simplifying, noticing that  $\tilde{L}^\phi = \frac{S_L}{(1-S_L)} \frac{(1-\alpha)}{\alpha}$  and rearranging we get 24.

Substituting the expression for  $\tilde{L}$  given in 24 in 23 we finally obtain:

$$(\phi - 1) \left( \sigma(1 - S_L) \frac{1 - v}{v} + S_L(1 - \sigma) \right) < \frac{\sigma S_L}{(1 - S_L)} \frac{\sigma + \chi - 2}{1 - \chi} \quad (26)$$

As the right hand side of this inequality is negative we need for the inequality to hold that the left hand side is negative as well, that is

$$\sigma < \frac{v S_L}{v + S_L - 1} \quad (27)$$

Notice the higher is  $v$ , the lower is  $S_L$ , the lower must be  $\sigma$  for 27 to hold. In conclusion a necessary and sufficient condition for stability to obtain is 26, which implies 27. Inspection of 26 shows that for any value of  $\sigma$  respecting condition



27 there is a value of  $\phi$  low enough to give rise to indeterminacy. Notice that stability is possible only if  $\phi$  is negative, since

$$\frac{\frac{\sigma S_L}{(1-S_L)} \frac{\sigma+\chi-2}{1-\chi}}{\left(\sigma(1-S_L) \frac{1-v}{v} + S_L(1-\sigma)\right)} = \frac{\frac{\sigma}{(1-S_L)} \frac{\sigma+\chi-2}{1-\chi}}{\left(\sigma(1-S_L) \frac{1-v}{v S_L} + 1 - \sigma\right)} < -1 \quad (28)$$

In fact the denominator of the fraction is always less than one, while the numerator is always less than minus one since  $\frac{\sigma+\chi-2}{1-\chi}\sigma < -1$  can be rewritten, given  $\sigma < 1, \chi < 1$ , as  $\sigma + \chi > 1$ , which is implied by condition 5 for concavity.

### 3 Conclusions

We have given general conditions under which a model with one good produced under constant returns to capital and decreasing returns to labour, i.e. featuring a downward sloping labour demand, can have a stable balanced growth path, so that sunspots can matter. We have shown that for indeterminacy we need a low elasticity of substitution of labour and capital and an intertemporal elasticity of consumption less than one i.e. that the marginal utility of consumption declines slowly with consumption.



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Figure 1

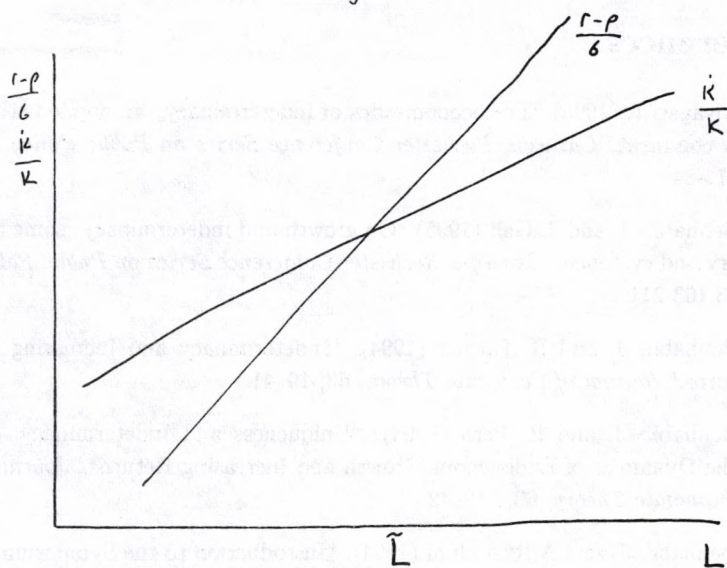
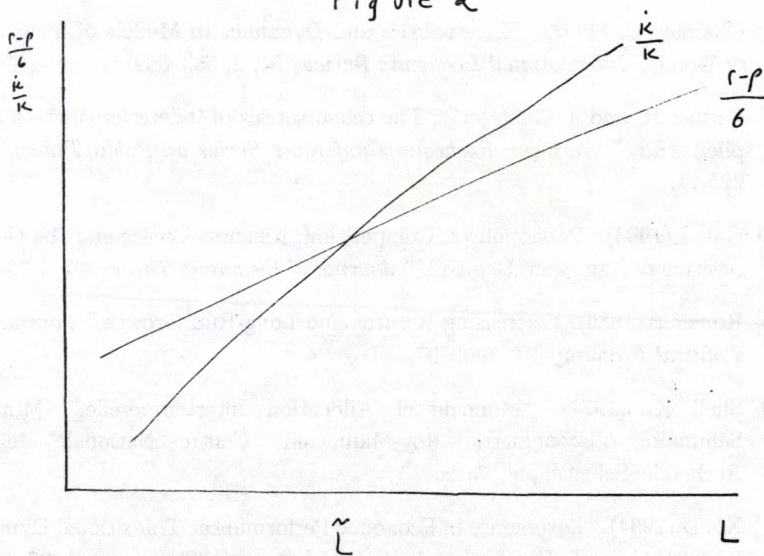


Figure 2





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